Indoor air quality

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INDOOR AIR QUALITY

Robert J. Milko

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Ottawa

28 August 1985

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INDOOR AIR QUALITY

INTRODUCTION

"Stop smoking and open the windows", the post-scriptum of a recently drafted review of chemical hazards and energy conservation in buildings,(1) although desirable, is not always possible.

Since the energy crisis of the 1970s, hermetically sealed buildings have been erected across North America and Europe, and the practice of smoking indoors continues. On the average the urban population spends 80-90% of its time in the home, workplace, automobiles, restaurants, theatres, etc., yet, until recently, studies into the quality of air have been largely restricted to the outdoors or the industrial workplace. Even though the available information suggests that elevated concentrations of some airborne contaminants are routinely encountered in indoor environments, and that total personal exposures are often better correlated with indoor than outdoor concentrations, the degree to which indoor air pollution represents a public health hazard has not been definitely established.(2)

The recognition of an indoor pollution problem has recently grown, resulting in research, publications and symposia on the topic. In particular, the "sick building syndrome" has expanded to enormous

(1) Michael Holiday and Associates, Chemical Hazards and Energy Conservation in Buildings, prepared for Health and Welfare Canada, Ottawa, August 1984, 137 p.

(2) J.D. Spengler and K. Sexton, "Indoor Air Pollution: A Public Health Perspective", Science, Vol. 221, No. 4605, 1 July 1983, p. 10.

proportions among the newly constructed large office complexes, but the actual cause or causes of the syndrome are still obscure and satisfactory remedial action is only partial or lacking altogether.

This paper will provide an overview of the complex and poorly understood problem of indoor air quality. First, I will characterize some of the major recognized pollutants, their sources and their potential effects on health and comfort. Second, I will explore the extent of the problem, using case studies as examples and third, I will examine the control and potential for control of indoor air quality.

INDOOR POLLUTANTS

Although many hundreds of compounds have been identified in indoor air (over 2,000 compounds in cigarette smoke alone(1)), only a dozen or so are considered when indoor pollution is assessed. These include radon and radon decay products, suspended particulates and fibrous particulates, sidestream tobacco smoke, formaldehyde, combustion by-products (e.g., polycyclic aromatic hydrocarbons, nitrogen dioxide, nitrous oxide, carbon monoxide, carbon dioxide), aeropathogens and allergens. A short summary of sources and types of indoor air pollutants is provided in Table 1.

Effects of these contaminants range from mild sinus irritation to irreversible toxic and carcinogenic maladies. Pollutants are either inhaled, ingested or absorbed. They may have an effect at their first point of contact, or after undergoing intermediate physical or metabolic changes. Their own behaviour helps shape the mechanism of their effects, which may occur independently, antagonistically or synergistically. Inhalation is the most important route by which air pollutants enter the body.

It can be seen from Table 1 that indoor air pollutants can have both indoor and outdoor sources and although indoor levels are often lower than outdoor levels for some pollutants, others may be produced predominantly indoors and at high concentrations in the absence of proper ventilation.

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(1) National Research Council (U.S.), Indoor Pollutants, National Academy Press, Washington, D.C., 1981, p. 150.

TABLE 1: SUMMARY OF SOURCES AND TYPES OF INDOOR AIR POLLUTANTS

Sources	Pollutant Types
OUTDOOR	
Stationary artificial sources	SO_2, CO, NO, NO_2, O_3, hydrocarbons, particulates
Motor vehicles	CO, NO, NO_2, lead, particulates
Soil	Radon
INDOOR	
Building construction materials	
Concrete, stone	Radon and other radioactive elements
Particleboard	Formaldehyde
Insulation	Formaldehyde, fiberglass
Fire retardant	Asbestos
Adhesives	Organics
Paint	Organics
Building contents	
Combustion appliances for heating and cooking	CO, NO, NO_2, formaldehyde, particulates
Copy machines	Organics
Water service, natural gas	Radon
Human occupants	
Metabolic activity	H_2O, CO_2, NH_3, organics
Biological activity	Microorganisms
Human activities	
Tobacco smoke	CO, NO_2, HCN, organics, particulates
Aerosol spray devices	Fluorocarbons, organics, CO_2
Cleaning and cooking products	Organics
Hobbies and crafts	Organics

Source: Michael Holiday and Associates, Chemical Hazards and Energy Conservation in Buildings, prepared for Health and Welfare Canada, Ottawa, August 1984, p. 39.

A. Radon-222 and Radon Daughters

The presence of Radon-222 (Rn-222) and its decay products has been identified as a major factor in the causation of lung cancer in uranium and non-uranium miners. Although miner exposure is two or three orders of magnitude higher than that "expected" for indoor settings, radon levels in poorly ventilated homes can reach significant levels. Rn-222 is continually emitted from soil, water and concrete building materials as a gas through the decay of radium-226, and is consequently trapped in buildings (particularly basements). Radon levels in buildings are therefore generally higher than those in outdoor air.

Although Rn-222 itself is an alpha-emitter, it is the shorter-lived alpha-emitting decay isotopes, polonium-218 and -214 which deliver the radiation dose associated with the carcinogenic properties of radon. Because these daughter isotopes are electrically charged when formed, they readily attach to suspended particulate matter, with which they are inhaled into the lungs.(1,2,3) Risk is proportional to exposure, which is a measure of both time and concentration. According to a recently drafted EPA (U.S.) proposal, a million homes in the United States are contaminated with radon and some 500-20,000 lung cancer deaths can be attributed to radon collecting inside buildings.(4)

A study of radon and radon daughters in Canadian homes found that radon levels were relatively low and no association was detected between radon levels and lung cancer mortality rates in the population of 18 Canadian cities. The Atomic Energy Control Board (AECB) has also set a primary criterion for radon levels based on an assessment of homes in uranium mining communities. These levels are subject to question. Health and Welfare Canada accepts a model of exposure and effects proposed by

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(1) Ibid., p. 57-76.

(2) Holiday and Associates (1984), p. 39-42.

(3) R.A. Wadden and P.A. Scheff, Indoor Air Pollution: Characterization, Prediction and Control, John Wiley and Sons Inc., New York, 1983, p. 32.

(4) Nuclear News, July 1985, p. 71.

Harley et al. and feels an accumulative dose at the AECB criterion level, when applied to this model, might well be considered too high. It would permit a projected dosage close to that which has been observed to cause increased lung cancer incidence in uranium miners.(1) Harley et al. have estimated that up to 20% of lung cancers among non-smokers and 5% among smokers may be a result of exposure to ambient radon levels. Health and Welfare have calculated that for a 33% and a seven-fold increase in indoor radon levels (respectively corresponding to retrofit air sealing of an existing house and what may be found in a super-tight house) significant increases in lung cancers could occur.(2) One must, of course, be cautious of such extrapolations.

B. Suspended Particulate Matter

Suspended particulate matter is generally considered to consist of all airborne solid and low-vapor-pressure liquid particles less than a few hundred micrometers in diameter (1 micrometer = 1×10^{-6} meters = 1 μm). Suspended particulate matter may be further categorized as total suspended particulates (TSP) or respirable particulates (RP). TSP is generally found in higher concentrations outdoors than indoors but most health concern is with RP which are particles with a diameter less than or equal to 5.0 μm. Approximately 90% of the particles of 5-μm in diameter enter and are deposited in the respiratory system.(3) Because the deposition of particles is related to their diameter, relatively long fibres having a small diameter (e.g. asbestos) may therefore be deposited into the lower regions of the respiratory tract.

The degree of physiological and/or pathological response seems to be related to the rate of removal of deposited RP's from the respiratory system, although a rapid response may be a result of the quality of the substance. Different clearance mechanisms operate in different regions of the respiratory tract. Rapid removal usually occurs in the

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(1) Holiday and Associates (1984), p. 59-60.

(2) Ibid., p. 102-103.

(3) National Research Council of Canada (NRCC), Effects of Inhaled Particles on Human Health: Influence of Particle Size and Shape, Publication No. NRCC 18564, Ottawa, 1982, p. 8.

nasopharyngeal and tracheobranchial regions although evidence suggests long periods of retention are possible in some portions of nasal passages (e.g. perforation of the nasal septum in potash miners and increased risk of nasal tumors amoung woodworkers and nickel refiners). Particles deposited in the tracheobranchial region are removed by mucocilliary transport to be either expectorated or swallowed (increasing the gastrointestinal dose of particles). Macrophage action is the major rapid clearance mechanism in the pulmonary region where length of fibres then becomes the major determining factor of a particle's retention period. Short fibres (5 µm in length) are rapidly and quantitatively engulfed whereas long fibres (20 µm) are never completely engulfed. Particles of intermediate length are sometimes engulfed. As with other adaptive responses, the mechanism of phagocytosis can become saturated.[1]

In general there are three mechanisms by which inhaled particles may evoke a biological response in the respiratory system: 1) a particle may be inherently toxic due to its physical and/or chemical nature; 2) a particle may be chemically inert but its presence may restrict the clearance of other toxic particles; and 3) a particle may act as a carrier for gases (e.g. radon), vapors or viruses which are toxic or pathological.

Since RP's are contained in cigarette smoke, consumer spray products and other indoor sources, their potential health implications are of concern but have been little studied. Most of the information currently available on biological response to particles is derived from industrial studies involving platelike particles (e.g. talc, mica) and fibrous material (e.g. asbestos, fibrous glass). It appears that the chemistry and mineralogy of the particles are important in fibrosis, i.e. a condition marked by an increase of interstitial fibrous tissue. For example, the data suggest that platy talc produces minimal cell toxicity, but when contaminated with silica or other cytotoxic materials, as is often the case, it causes a tissue response related to the contaminants rather than to the talc particles. Additionally, talc is often found to be contaminated with asbestos fibres.

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(1) Ibid., p. 11.

C. Asbestos and Fibrous Particles

Asbestos is a generic term that applies to naturally occurring, hydrated mineral silicates that are separable into flexible, incombustible fibres possessing a large length to diameter ratio. Six varieties are recognized of which four (amosite, crocidolite, chrysotile and anthophyllite) are found in commercial ore deposits. Approximately 600,000 tons was used in the U.S.A. in 1979 of which over 90% was chrysotile imported from Canada.(1) The consequences of asbestos fibre inhalation and retention in the human lung are fibrosis, bronchogenic carcinoma, mesothelioma of the pleura and peritoneum, and carcinoma of the gastrointestinal tract and other sites such as the larynx.(2) Asbestosis is the term more commonly associated with diffuse fibrosis of the lung and frequently of the pleural membranes. This may eventually lead to death from cardiorespiratory failure. Asbestosis has been shown to occur in persons exposed to any variety of commercial asbestos (i.e. all varieties are carcinogenic).

Studies have shown that the physical and mechanical characteristics of asbestos fibres are more responsible for their cytotoxicity and fibrogenicity than are their chemical composition. Increasing fibre length (20 μm in length) and decreasing diameter were related to carcinogenicity. Several studies have shown increased mesothelioma rates among persons living near asbestos-production facilities and shipyards and among family members living with asbestos exposed workers.(3,4,5,6)

Because of the widespread use of asbestos in ceiling and floor tiles, pipe insulation, cements and insulating material there is a large potential for public exposure.(7,8) Although more than 85% of

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(1) National Research Council (U.S.) (1981), p. 112.

(2) NRCC (1982), p. 78.

(3) Spengler and Sexton (1983), p. 13.

(4) Wadden and Scheff (1983), p. 78.

(5) NRCC (1982), p. 78-85.

(6) National Research Council (U.S.) (1981), p. 339-345.

(7) Wadden and Scheff (1983), p. 26.

(8) Spengler and Sexton (1983), p. 13.

asbestos is immobilized in strong building materials, fibres will be released when sufficiently disturbed. Additionally fibre release in "fallout" is continuous, low-level and persistent and may occur as the adhesive binder degrades. The rate of fallout may vary due to structural vibrations, humidity changes and air movements.

With the phasing out of asbestos in insulation, fibrous glass, which includes mineral and glass wool, has become a suspect carcinogen. Although no epidemiological studies link these substitutes with lung cancer there is suggestion from animal studies that fibrous glass contributes to disease development. In fact there has been insufficient experience and time in working with such fibres to judge their hazard adequately. It should be noted, however, that fibre lengths and diameters are similar to those of asbestos and it is this aspect which appears to be most responsible for the carcinogenic nature of asbestos.

D. Tobacco Smoke

A distinction can be made between mainstream smoke and sidestream smoke in the contaminants derived from the combustion of tobacco. There is no dispute that the concentrations of almost all constituents are far greater in mainstream smoke inhaled by the smoker, but, if one considers that sidestream smoke is produced 96% of the total smoking time and that many pollutants are filtered out by the smoker's lungs, the emission factors for sidestream smoke appear to be more useful for characterization of indoor environments where smoking is allowed.

Table 2 shows the mass per cigarette and the ratio of side-stream to mainstream smoke for specific compounds. Substantial evidence indicates that many substances in sidestream smoke are increased because of the different combustion temperatures generated. Cigarette smoking in enclosed areas increases concentrations of particles, gases with carbon monoxide, nicotine, nitrosamines and benzopyrene being the most affected. Studies have also shown that smoking was found to be the major source of indoor respirable particulate matter in homes and that smoke particles

TABLE 2: COMPOSITION OF MAINSTREAM AND SIDESTREAM SMOKE

Characteristic or Compound	Concentration, mg/cigarette[a] Mainstream Smoke (1)	Sidestream Smoke (2)	Ratio, 2:1
General characteristics:			
Duration of smoke production, s	20	550	27.5
Tobacco burned	347	411	1.2
Particles, no. per cigarette	1.05×10^{12}	3.5×10^{12}	3.3
Particles:			
Tar (chloroform extract)	20.8	44.1	2.1
	10.2[b]	34.5[b]	3.4
Nicotine	0.92	1.69	1.8
	0.46[b]	1.27[b]	2.8
Benzo[a]pyrene	3.5×10^{-5}	1.35×10^{-4}	3.9
	4.4×10^{-5}	1.99×10^{-4}	4.5
Pyrene	1.3×10^{-4}	3.9×10^{-4}	3.0
	2.70×10^{-4}	1.011×10^{-3}	3.7
Fluoranthene	2.72×10^{-4}	1.255×10^{-3}	4.6
Benzo[a]fluorene	1.84×10^{-4}	7.51×10^{-4}	4.1
Benzo[b/c]fluorene	6.9×10^{-5}	2.51×10^{-4}	3.6
Chrysene, benz[a]anthracene	1.91×10^{-4}	1.224×10^{-3}	6.4
Benzo[b/k/j]fluoranthrene	4.9×10^{-5}	2.60×10^{-4}	5.3
Benzo[e]pyrene	2.5×10^{-5}	1.35×10^{-4}	5.4
Perylene	9.0×10^{-6}	3.9×10^{-5}	4.3
Dibenz[a,j]anthracene	1.1×10^{-5}	4.1×10^{-5}	3.7
Dibenz[a,h]anthracene, ideno-[2,3-ed]pyrene	3.1×10^{-5}	1.04×10^{-4}	3.4
Benzo[ghi]perylene	3.9×10^{-5}	9.8×10^{-5}	2.5
Anthanthrene	2.2×10^{-5}	3.9×10^{-5}	1.8
Phenols (total)	0.228	0.603	2.6
Cadmium	1.25×10^{-4}	4.5×10^{-4}	3.6
Gases and vapors:			
Water	7.5[c]	298[d]	39.7
Carbon monoxide	18.3	86.3	4.7
	—	72.6	—
Ammonia	0.16	7.4	46.3
Carbon dioxide	63.5	79.5	1.3
NO_x	0.014	0.051	3.6
Hydrogen cyanide	0.24	0.16	0.67
Acrolein	0.084	--	—
	--	0.825	--
Formaldehyde	—	1.44	--
Toluene	0.108	0.60	5.6
Acetone	0.578	1.45	2.5
Polonium-210, pCi	0.04-0.10	0.10-0.16	1-4

[a]Unless otherwise noted. [b]Filtered cigarettes.
[c]3.5 mg in particulate phase; rest in vapor phase.
[d]5.5 mg in particulate phase; rest in vapor phase.

Source: National Research Council (U.S.), Indoor Pollutants, National Academy Press, Washington, D.C., 1981, p. 157.

inside buildings are almost all in the RP range.(1) Sidestream RP's are persistent with 75% remaining in suspension in a test chamber after 2.5 hr.(2)

Considerable experimental and epidemiological evidence points out the association of involuntary smoking and adverse health conditions. These can range from mild eye and nose irritation to increased risk of developing lung cancer. One survey of over 20,000 federal employees in the United States found high prevalences of conjunctival irritation (47.7%), nasal discomfort (34.7%) and cough, sore throat and sneezing (30.3%) in those exposed to cigarette smoke. A clinical study indicates that the gas-phase constituents are responsible for annoying the involuntary smoker but that the irritation is caused principally by the particulate phase.(3)

It has also been clinically demonstrated that involuntary smoking by patients with coronary heart disease results in a reduced time before angina occurs after exercise. Additionally chronic exposure has been found to significantly reduce small-airways function in nonsmokers, to be an exacerbating factor in childhood asthma and to increase morbidity (mostly due to respiratory disease) in Finnish children.(4)

One study of mortality records of over 90,000 nonsmoking wives in Japan showed that wives of heavy and light smokers had a relative risk of developing lung cancer, 2.1 and 1.6 times that of wives of nonsmoking husbands. The same effect was noted for a study for a small number of nonsmoking Greek women. A similar study of 177,000 nonsmoking American women, however, did not show a statistically significant difference

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(1) K. Sega et al., "Indoor-Outdoor Relationships for Respirable Particles, Total Suspended Particle Matter and Smoke Concentrations in Modern Office Buildings", in Indoor Air, Vol. 2, Swedish Council for Building Research, Sweden, 1984, p. 189-194.

(2) Wadden and Scheff (1983), p. 58.

(3) Holiday and Associates (1984), p. 60-61.

(4) Wadden and Scheff (1983), p. 22.

between those married to smokers and nonsmokers, though the rate for involuntary smokers was higher.(1,2)

The National Academy of Sciences states in its report on indoor pollutants:

> The constituents of tobacco smoke are well-documented as hazardous, the prevalence of population exposure is very high, and there is an increased incidence of respiratory tract symptoms and functional decrements (decreases) in children residing in homes with smokers, compared with those homes without smokers. These considerations and recent evidence of increased lung cancer rates among non-smoking women living with smoking husbands have led us to conclude that indoor exposure to tobacco smoke has adverse effects. Public policy should clearly articulate that involuntary exposure to tobacco smoke ought to be minimized or avoided where possible.(3)

E. Combustion Products

The major products of the combustion of hydrocarbon fuels are carbon dioxide (CO_2) and water. Although not necessarily considered pollutants themselves, their presence is often used as an indicator of other more toxic compounds such as carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2) and aldehydes. Aside from tobacco smoking, the major sources of combustion products are unvented or non-maintained indoor space heaters, gas stoves and water heaters and fossil fuel furnaces.

Elevated levels of CO exceeding the one hour environmental standard (U.S.) of 35 ppm have been measured in homes with gas stoves. NO and NO_2 levels well above ambient levels have been reported for gas cookers, unvented kerosene-fired space heaters (becoming increasingly popular in Canada) and for a forced-air gas-fired central heating

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(1) Ibid. (1984), p. 62-63.

(2) Wadden and Scheff (1983), p. 22.

(3) National Research Council (U.S.) (1981), from Spengler and Sexton (1983), p. 12.

system.(1) Houses with gas stoves, although producing combustion gas levels lower than space heaters, have shown maximum levels of combustion gases significantly higher than those where electric stoves are used. Levels tend to be periodic, in conjunction with the periodicity of cooking, but unvented pilot lights produce a continual low level addition of combustion gases. Localized ventilation hoods provide a simple and effective means of dealing with gas stove emissions.

A fossil-fuel fired furnace should not pollute indoor air, but small cracks in heat exchanges, chimneys with poor drafts and leaking combustion chambers can contribute to indoor pollutants and have been known to cause fatalities. Another combustion source of emerging interest is the wood stove. Combustion is usually incomplete and emission potential is high, particularly with leaks, improper operation of flue systems and reduced draft settings. In one study in homes with wood stoves, levels of TSP and benzopyrene were respectively three and five times higher than when wood was not burned.(2) Underground attached garages can also contribute to indoor CO, NO_2 and particle concentrations.

1. Carbon Dioxide

As a natural product of respiration CO_2 has no toxic effect at atmospheric concentrations below 1.5% (15,000 ppm). But, because CO_2 is used as a gross indicator of indoor pollutants and its level has been related to the frequency of occupant complaints in office buildings, for example, CO_2 levels are important in understanding the effects of indoor air quality. The Ontario Ministry of Labour Occupational Health Branch has determined the effects of various levels of CO_2 as follows:

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(1) Wadden and Scheff (1983), p. 52-58.

(2) Ibid., p. 58.

Carbon Dioxide (PPM)	Comments
Less than 600	Adequate fresh air
600-800	There may be occasional complaints, particularly if the air temperature rises
800-1000	Complaints are more prevalent
1,000	Insufficient make-up air, complaints are general

Source: G.S. Rajhan, "Indoor Air Quality and CO_2 Levels", in Occupational Health in Ontario, Vol. 4, No. 4, 1983, p. 162.

These CO_2 levels give an indirect evaluation of the ratio of fresh air to recirculated air in the system. Levels above 1000 ppm indicate that the building's HVAC (heating, ventilation and air conditioning) system is supplying insufficient make-up air.

2. Carbon Monoxide

Carbon monoxide is a chemical asphyxiant gas arising from the formation of carboxyhemoglobin (HbCO) in the blood. Because red blood cells' affinity for CO is 200 to 250 times that of oxygen, the amount of available oxygen for tissue respiration is reduced in the presence of CO. Acute effects of high concentrations are readily determined (death) but as with most toxicants, the chronic effects of low exposure are harder to identify. The base level of HbCO in blood is from 0.5 to 0.8% resulting from endogenous physiological/biochemical production. This level might be expected in a nonsmoker in a rural environment; an urban dwelling nonsmoker would have levels of 1.0 to 1.5%, while a pack-a-day smoker would have levels of 4 to 5%. It has been demonstrated that HbCO levels of 3-5%

aggravate symptoms in patients with cardiovascular disease and adversely affect the ability to detect small, unpredictable environmental changes (vigilance). That such a small increase in level has this effect may be cause for arguing that a long-term exposure of CO may lead to the degradation of the cardiovascular system.[1]

Indoor CO concentrations are often higher than outdoor concentrations, and usually higher in homes than public buildings. Exceptions are under conditions of heavy smoking, in office buildings with underground garages or improperly designed and/or malfunctioning HVAC systems.[2]

3. Nitrogen Oxides

Both nitric oxide (NO) and nitrogen dioxide (NO_2) are formed from atmospheric nitrogen and oxygen in the high-temperature part of a flame, where NO is produced as a precursor to, and in much higher concentrations than NO_2. Acute toxicity is not expected from the relatively low concentrations of NO_2 that are generated, but elevated levels above the 0.05 ppm standard (U.S.) are not unusual in kitchens where gas is used for cooking. At those concentrations, NO_2 may reversibly affect adaptation of vision to the dark (0.075-0.76 ppm) and produce eye irritations. Concentrations in the range of 50-150 ppm can produce chronic lung disease and above 150 ppm can be lethal.[3] The Canadian Ambient Air Quality standard for NO_2 defines 0 to 0.22 ppm averaged over one hour and 0 to 0.11 ppm averaged over 24 hours as being the acceptable range for exposure; the desirable range is 0 to 0.032 ppm. Animal studies have indicated that continuous exposure to NO_2 is more toxic than intermittent exposure and that the toxic hazard is primarily determined by the peak, not the average concentration, an important aspect when considering ambient standards.[4]

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(1) Holiday and Associates (1984), p. 66.

(2) National Research Council (U.S.) (1981), p. 32.

(3) Wadden and Scheff (1983), p. 15.

(4) Holiday and Associates (1984), p. 72.

Although NO *per se* has no known irritant properties, it does produce hypoxemia which may occur when elevated levels of CO are present. This is often the case as both NO and CO are produced in combustion. Some studies, however, have linked chronic exposure of nitrogen oxides produced by gas stoves with increased respiratory disease in children, the younger the more susceptible. In these studies, concentrations of NO_2 measured were in the order of 0.1 ppm. It should be noted, however, that exposure to nitrogen oxides would be mainly to NO and incidence of the disease could possibly correlate with NO levels.

F. Formaldehyde

Formaldehyde (HCHO) is an important industrial chemical used to produce synthetic urea- and phenol-formaldehyde resins. These in turn are used as adhesives in particleboard, fibreboard, plywood and laminates, coating processes, paper products, foam for insulation (UFFI) and in some fabrics. When wood panels are manufactured, a small excess of formaldehyde is often added to ensure cross-linking within the resin polymer. Because of this excess and because urea-formaldehyde resins easily hydrolyze, such products can emit formaldehyde gas for a long period after manufacture. Emission rates are dependent on both humidity and temperature (Figure 1). The higher cost and darker colour of the more stable phenol-formaldehyde prohibit its use from most applications.[1]

The degree to which formaldehyde may be emitted from UFFI is directly related to the composition of the precursor resin and the extent of breakdown reactions in the foamed product (which depends on the *in situ* acidity of the foam). It has been shown that extractable formaldehyde may differ by a factor of 10 between different formulations.[2] Numerous surveys in the United States, Canada and Europe have shown urea-formaldehyde levels in the home, as a result of UFFI, higher than the individual country's guidelines or standards. Health and Welfare Canada has suggested,

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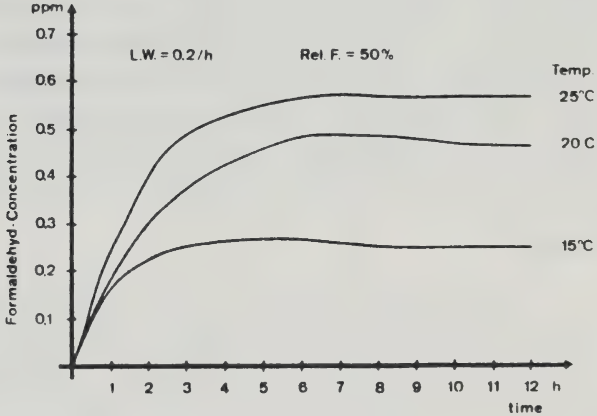
(1) Ibid., p. 53-57.

(2) Wadden and Scheff (1983), p. 66.

FIGURE 1: INFLUENCE OF TEMPERATURE ON FORMALDEHYDE RELEASE FROM 30 m^2 OF UNCOATED PARTICLEBOARD (CONSTANT HUMIDITY)



Source: H. Wanner and M. Kuhn, "Indoor Air Pollution by Building Materials", in Indoor Air, Vol. 3, Swedish Council for Building Research, Sweden, 1984, p. 40.

as a guideline, 0.1 ppm formaldehyde as the upper limit for acceptable air quality in homes. It should be noted that most homes without UFFI rarely have formaldehyde levels in excess of 0.05 ppm,(1) while concentrations in excess of 0.1 ppm appear to be common in homes insulated with UFFI.

The eyes, respiratory tract and skin are the organ systems predominantly affected in acute exposures to formaldehyde (Table 4). Although the mutagenicity and carcinogenicity of formaldehyde have been demonstrated, at least in experimental rats, extrapolation to humans is questionable. To date, no epidemiological studies have indicated any connection between exposure and cancer incidence.

It is, however, the chronic effects of formaldehyde exposure that are of concern in an assessment of indoor air pollution. Some people may become sensitized to formaldehyde and experience unusually severe reactions when re-exposed. Such individuals can detect the odour at levels 20 times lower than the general population and may experience eye irritation at levels some 200 times lower. In some cases, this hyper-susceptibility is an allergic response, not fully understood, but also of importance when considering standards and the impact of air quality on health and comfort.

G. Organic Compounds

The organic compounds most commonly found in the indoor atmosphere are components of commercial solvents. One study examining 42 commonly used building materials showed that, on the average, 22 compounds were emitted from <u>each</u> building material. According to the mathematical model developed from the study, the 10 materials that contributed most to the total concentration of solvent vapours and gases were:(2)

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(1) Holiday and Associates (1984), p. 85.

(2) Lars Molhave, "Indoor Air Pollution Due to Organic Gases and Vapours of Solvents in Building Materials", in Environment International, Vol. 8, 1982, p. 124.

TABLE 3: ACUTE EFFECTS OF FORMALDEHYDE EXPOSURE IN HUMANS

Concentration (ppm)	Effects
>100	Death
50-100	Pulmonary edema, inflammation, pneumonia
10-15	Exposure unbearable, even for a few minutes; heavy lachrymation and severe pain on breathing
5	Marked discomfort: sneezing, coughing; irritation to respiratory tract, eyes and skin; headaches
2	Minimal discomfort: perhaps slight stinging of eyes
1	Odour threshold in normal individuals
0.06	Odour perceptible by some atopic individuals
0.01	Eye irritation reported in some atopic individuals

Source: Michael Holiday and Associates, Chemical Hazards and Energy Conservation in Buildings, prepared for Health and Welfare Canada, Ottawa, August 1984, p. 79.

Source	Concentration (mg/m^3)
EVA glue	1,530
PVA filler	58
PVA glue	34
Floor textile	9.0
Polystyrene foam	7.9
Isocyanate varnish	7.7
PVC floor covering	3.8
Sealing agent	3.4
Acryllatex paint	2.4
Rubber floor covering	2.3

Of the 52 compounds found in total, no satisfactory toxicological information on the potential health effects of most of the compounds was available. Although levels of individual compounds were below threshold level values (TLV; Danish and U.S.), the concentration of vapours from EVA glue was extremely high. Thirteen of the 52 compounds are known or suspected human carcinogens. Another study by Molhave identified vapours from 79 organic compounds in the 14 locations examined. Even if individual compound levels are low, the large number and complexity of mixtures are of primary concern.

A Swedish study of the neurotoxic effects of occupational exposure to organic solvents among car and industrial spray painters concluded that the exposed subjects exhibited more neurasthenic symptoms than the reference subjects: they performed poorly on psychological tests of memory, manual dexterity, perceptual speed and reaction capability; they also had slower nerve conduction velocities and lower nerve action potentials. The level of exposure in this study, expressed as a <u>sum</u> of all the compounds present, was only 20-30% of the sum of the Swedish TLV.(1) Another study of Swedish painters showed a mortality rate from chronic bronchitis and emphysema 50% above that expected.

The complexity of organic compounds and their prevalence constitutes an enormous task in standard setting and ventilation requirements for adequate indoor air quality. Toxic effects, however, are sufficiently similar for the majority of compounds that a single, surrogate

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(1) S. Elofsson et al., "Exposure to Organic Solvents", Scand. J. Work Environ. Hlth., Vol. 6, No. 239, 1980, in Holiday and Associates (1984), p. 74-75.

measure of organic vapour pollution may be appropriate.(1) Such a total non-methane hydrocarbon (TNMHC) standard for indoor air is the ASHRAE 62-73 (American Society of Heating, Refrigerating and Air-Conditioning Engineers) limit of 1.8 mg/m^3.

H. Airborne Microorganisms and Allergens

The varied and complex organic structures of biogenic pollutants reduce their measurement to a simple and non-comprehensive estimate of total viable particles (TVP) or colony forming particles (CFP). This results in an inadequate, quantitative data base. Furthermore, these measurements ordinarily reflect bacterial activity, do not include pollen or viruses and often exclude fungal spores. This is unfortunate because, on the basis of their health effects, airborne viruses and bacteria might be considered the most important form of air pollutant.(2,3) According to the U.S. National Health Survey, respiratory ailments account for more than half of all acute conditions including illnesses and injuries, and are the fifth largest cause of death.

Inhalation of biological aerosols discharged by people and animals is viewed as a primary mechanism of contagion. As well, air conditioners, cool-mist humidifiers, fan coil units, nebulizers, flush toilets, ice machines and carpets have been identified as locations where pathogenic organisms concentrate and may later be released as viable aerosols. Legionnaire's disease (Legionella pneumophila) and humidifier fever (Acinetobacter infections) are well documented examples of "air conditioning-related" diseases.

Pollen, molds, mites, animal dander, fungi, algae and insect parts have all been confirmed as airborne antigens that evoke human allergic

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(1) Holiday and Associates (1984), p. 75.

(2) L. Hinkle and S. Murray, "The Importance of the Quality of Indoor Air", in Bull. N.Y. Acad. Med., Vol. 57, No. 10, December 1981, p. 830.

(3) Spengler and Sexton (1983), p. 12.

responses. Allergic reactions can occur on the skin and in the nose, airways and alveoli. Although increasingly recognized as important causes of allergic lung diseases, occupational agents are not as prevalent as causes of these diseases as are allergens in the home. Many allergens are temperature- and humidity-dependent. Examples are: house dust mites which flourish around 25°C and relative humidities above 45%, whose excreta invokes allergic bronchial responses and Aspergillus fumigatus, a mold associated with allergic bronchopulmonary aspergillosis. Although thermotolerant, A. fumigatus has been found to flourish in Swedish dwellings where relative humidity is above 75%.(1) Other fungal taxa recovered inside buildings are similar to those collected out-of-doors but, because high humidity favours the growth of molds and fungi, tightly-sealed buildings in humid climates are more prone to allergenic problems.

With a greater frequency, the literature suggests that reduced ventilation and untreated, recirculated air may increase concentrations of microorganisms. Because prolonged exposure to some chemicals and antigens can cause sensitization, it is possible that reduced fresh air might lead to increased rates of infection and allergy. One author suggests that more than 10% of a population have an increased risk of developing allergies during a stay in an environment with a high concentration of allergens.(2) The problem remains that little is known about sources, concentrations and survival rates of many aeropathogens indoors.

OTHER POLLUTANTS AND SOURCES

One must bear in mind that it is virtually impossible to examine an exhaustive list of indoor air pollutants and sources. Some

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(1) K. Holmberg, "Mould Growth Inside Buildings", in Indoor Air, Vol. 3, Swedish Council for Building Research, Sweden, 1983, p. 253-256.

(2) I. Andersen et al., "A Strategy for Reduction of Toxic Indoor Emissions", in Environment International, Vol. 8, 1982, p. 12.

pollutants not previously examined warrant attention due to their prevalence in specific environments.

Both photocopying machines and domestic and commercial electrostatic air cleaners have been shown to be indoor sources of ozone. Ozone is a pulmonary irritant that affects the mucous membranes, other lung tissues and respiratory function. There are also reports that some toners used in photocopying machines contain mutagens, possibly due to trace amounts of nitropyrene.

Domestic activities are another source of hazardous materials. Asbestos may be discharged from hair dryers; air fresheners release organic compounds directly into the atmosphere (e.g., paradichlorobenzene; chlorinated benzenes on combustion produce dioxins); and cleaning compounds can release either chlorine or ammonia gas and other organic vapours. Of particular note are aerosol products whose propellants vary but which may include propane, isobutane, trichlorofluoromethane and dichlorodifluoromethane. Measured concentrations of these propellants collected in a one cubic metre chamber during and after 12-second spray applications represented "worst reasonable conditions." It is worth noting that the diameters of aerosol products are in a range of 0.04-0.06 μm and, because of their size, have a high potential for deposition in alveolar lung spaces.(1)

CHEMICAL SUSCEPTIBILITY

People differ widely in their susceptibility to air pollutants. On exposure, some will experience simply a general malaise or no effect, while others may experience more serious and incapacitating effects. A term used to classify this condition is chemical hypersusceptibility if the reaction is to chemicals and hypersensitivity if specific to immunogenic (i.e., allergic-type) hypersusceptibility. Although

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(1) Wadden and Scheff (1983), p. 73-74.

there is extensive literature dealing with hypersusceptibility, little information except for case studies is available with respect to air pollutants as the causal agent. Part of the problem is that reported symptoms are as varied as the chemical agents and the exposure situations that cause them. If estimates of the population who may have inhalant allergies is correct (15-20%), the syndrome should be considered when air pollution standards are set.(1)

VENTILATION SYSTEMS AND HEALTH

A high concentration of biogenic pollutants is the major health problem directly related to ventilation systems. The majority of ventilation-related diseases are, ironically enough, associated with hospitals and medical centres, most probably because of the large numbers of immuno-suppressed patients. These include Legionella pneumophila, Aspergillus and thermophilic actinomycetes as well as Myobacterium tuberculosis, measles, rubella and varicella.

Certain parts of a ventilation system are critical to understanding the spread of airborne pathogens. These include:

1) cleanliness of incoming air
2) quality and condition of filters
3) contamination in ducts
4) contamination of air by on-line or other free-standing humidifiers.

In particular, if microorganisms are introduced into the water systems of cooling towers and evaporative condensers, the internally-produced aerosols used in evaporative cooling can provide the appropriate conditions for proliferation. As Legionella is able to contaminate tap water, humidifier reservoirs are also potential sites of proliferation.

Control of airborne infections is largely attainable by either removing or isolating the reservoir of infection. In the case of external microbial pollution, for example, the proliferation of Aspergillus

(1) Holiday and Associates (1984), p. 86-88.

in air ducts, careful location of air duct intakes and use and maintenance of good quality filters is essential. Aspergillus infections have been related to air ducts located over construction sites because proliferation occurs in the soils being excavated. L. pneumophila presents more difficult problems. To date the optimum disinfectant has yet to be determined although hyperchlorination is used to some extent. For hospitals, the removal of all humidifiers has been recommended as the only effective safeguard.(1)

VENTILATION AND COMFORT PROBLEMS

Comfort-related indoor air quality issues, differentiated from health problems, make up the greater proportion of complaints from building occupants. These comfort-related complaints, often referred to as the "sick building syndrome", are usually "non-specific" and include eye irritation, upper respiratory complaints, fatigue, perceived stuffiness of air, headache and in some cases, nausea. The severity usually increases as the day and week progress and disappear when an occupant is not in the building. Symptoms are normally found in fairly new, refurbished or retrofitted buildings, where there is an element of recirculated air, and where workers have little or no control over regulation of temperature, humidity and lighting at their work location. An examination of a familiar Ottawa-Hull example of the sick building syndrome at Les Terrasses de la Chaudière will help to illustrate some of the problems and solutions attempted.

In the early stages of investigation in 1979 at Les Terrasses de la Chaudière, the problems illustrated by health surveys were not readily answered. On further study, Health and Welfare determined that formaldehyde levels were high (0.017 to 0.06 ppm) but still below the TLV guideline (UFFI was not used as insulation in the building). Organic vapour levels were

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(1) F.M. Laforce, "Airborne Infections and Modern Building Technology", in Indoor Air, Vol. 1, Swedish Council for Building Research, Sweden, 1983, p. 109-127.

very low, 1% or less of the permissible levels for occupational exposure. Consequently, ventilation of outdoor air was increased but it was unable to reduce the HCHO levels below 0.017 ppm and the complaints continued. Eventually, by April 1981, an energy saving directive was overridden and the ventilation system became operational 24 hours a day and seven days a week. The following are some of the problems corrected and reported in a 1981 PWC bulletin. Apparently many of the problems were identified earlier but not corrected:(1)

1) The variable-air-volume (VAV) boxes controlling air flow into office diffusers for the interior of the building were set to close completely if the ambient temperature fell below a certain limit. Modifications were ordered so the VAV boxes were to be open at least 40% of the time.
2) Air vanes were improperly directing air into return air slots in the ceiling (shortcircuiting).
3) Partition layouts were/are having an effect on circulation patterns. Occupants of closed offices, presumably designed with proper ventilation, "report few symptoms overall, those in the open have rather more symptoms, including those related to stress, and those in cubicles have many symptoms and complained particularly of irritant rather than of general or stress problems".(2)
4) Leakage was found in the Z-duct heat exchangers resulting in some air recirculation even when dampers were in a closed non-recirculation position. These dampers were permanently sealed off.
5) Some contamination of the ventilation air by the exhaust from the major printing area was found and modified.
6) Discrepancies between the specified air handling capacity of the supply fans and their measured output were found.

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(1) R.H. Ferahin, "Indoor Air Pollution - Some Canadian Experiences" in Indoor Air, Vol. 1, Swedish Council for Building Research, Sweden, 1984, p. 207-217.

(2) J.C. McDonald, Investigation of Employee Health Complaints at Les Terrasses de la Chaudière, Final Report to TB/PSAC Steering Committee, Ottawa, July 1984, p. 36.

7) Exhaust air was leaking into the penthouse.

8) Inadequate humidity control in the summer was found and is still a problem.

Even though these corrections should have resulted in some improvements in air quality, complaints continued and were further investigated by the McDonald Study previously referenced. As of July 1984, it appears that adequate ventilation to all floors was still not achieved and ventilation was not uniformly distributed on any one floor. Such buildings with the open-plan office concept appear to need the greatest attention since good air movement rarely extends below the tops of partitions. One author suggests that somewhere between 5% and 75% of office problems could be substantially reduced with better ventilation.[1]

A recent draft report by the Canadian Intergovernmental Energy Management Committee (C.I.G.E.M.C.) recommends a four-fold increase of minimum outside air from 2.5 l/sec/person to 10 l/sec/person.[2] This would bring the fresh air level into compliance with the A.S.H.R.A.E. (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Standard 62-1981, for the minimum outside air for buildings where smoking is allowed. Other recommendations are "that the total air circulated within the workspace be not less than 7.5 l/sec/m^2 to allow for adequate mixing and dilution of contaminants, that mechanical ventilation systems for all new buildings be capable of delivering 100% outside air when it is economical to do so and that operating strategies be developed for buildings to purge the building of pollutants at certain times of the day".[3]

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(1) P.A. Breysse, "The Office Environment - How Dangerous?", in Indoor Air, Vol. 3, Swedish Council for Building Research, Sweden, 1984, p. 315-320.

(2) C.I.G.E.M.C., Initial Report of the Task Force on Indoor Air Quality, (draft), Ottawa, June 1985, p. 1-11.

(3) Ibid., p. 7.

Although the importance of adequate fresh air is being recognized, the specific reasons for the complaints are still not understood. Relationships between ventilation rates and pollutant concentrations are being examined but scientific investigation is at an infancy stage. According to Figure 2, the indoor level of a pollutant which is assumed to be higher than an outdoor level, will approach the outdoor level with a ventilation rate effecting 4 to 6 air changes per hour (ach). For reference, in new, energy efficient houses, the air exchange rate may be as low as 0.05 ach while in older houses, because of leakage, air exchange rates can be as high as 2 ach.

Based on this model, the trade-off of retrofitting houses poses some interesting questions. It is unlikely that a house can be sealed below 0.5 ach. Because of this value's position on the asymptotic curve of Figure 2, retrofitting to 0.5 ach would result in an increase of the concentration of pollutants by a maximum of 33%. For comparison, a 36% saving in energy could be achieved by lowering the air exchange from the average exchange rate of 1.75 ach to 0.8 ach (resulting in even less of a pollutant increase). Although this energy saving with the "minor" pollutant increase is suggested as a reasonable trade-off,(1) the levels of pollutants must be known and such an analysis should only be made if initial levels were low.

Other models suggest a more complex relationship between ventilation rate and indoor concentrations. While theoretically derived relationships usually indicate that indoor concentrations of pollutants increase rapidly as air exchange rates become low, the converse is not necessarily thought to be true. For example, the coupling between formaldehyde source strength and indoor concentration reduces the impact of ventilation.(2) As well, different pollutants are dispersed at various

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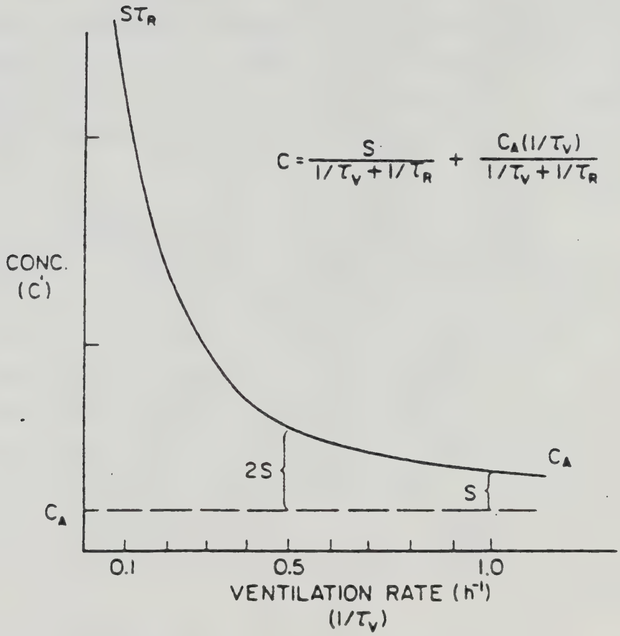
(1) Holiday and Associates (1984), p. 98-100.

(2) W.J. Fisk, "Ventilation for Control of Indoor Air Quality" in Indoor Air, Vol. 5, Swedish Council of Building Research, Sweden, 1984, p. 187-192.

FIGURE 2: THE RELATIONSHIP BETWEEN VENTILATION RATE AND INDOOR POLLUTANT CONCENTRATIONS



C = concentration of pollutant indoors
C_A = ambient (outdoor) concentration
S = source strength (e.g., in mg/hr)
τ_R = removal constant; $1/\tau_R$ = removal rate
τ_V = ventilation constant; $1/\tau_V$ = ventilation rate

Source: Michael Holiday and Associates, Chemical Hazards and Energy Conservation in Buildings, prepared for Health and Welfare Canada, Ottawa, August 1984, p. 99.

rates and the assumption of uniform mixing throughout the environment may lead to significant errors in estimating the human exposure.[1] In some and possibly most instances, attention to pollutant removal processes other than ventilation is recommended.

Additionally there is a growing concern based on evidence which indicates that synergistic effects of combinations of pollutants may be responsible for problems even when low individual concentrations are measured.[2,3] Again we are confronted with the need to make judgments with an inadequate data base.

CONTROL OF INDOOR AIR QUALITY

Although not specifically emphasized to this point, it should be quite clear that the major contributing factors to poor indoor air quality are the attempts at energy conservation.

A. Residential Sector

Although various approaches to energy conservation in residential buildings are used, changes to one system may well have consequences in another and/or may result in more than one problem. For example, reduced air flow may lead to higher humidity levels and increased growth of mold and mildew (allergens). The air flow may also be insufficient to supply air to furnaces which may result in poor efficiency and a tendency to draw in air from sources such as a basement drain, possibly bringing in sewer gases and radon into the building.[4] Integrated methods of energy conservation and their effects on indoor air quality are not as fully developed for residential buildings as in the commercial sector.

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(1) H.T. Maki and James E. Woods, "Dynamic Behaviours of Pollutants Generated by Indoor Combustion", in Indoor Air, Vol. 5, Swedish Council of Building Research, Sweden, 1984, p. 73-78.

(2) Spengler and Sexton (1983), p. 9-17.

(3) Turiel et al., "The Effects of Reduced Ventilation on Indoor Air Quality in an Office Building" in Atmospheric Environment, Vol. 17, no. 1, 1983, p. 51-64.

(4) Holiday and Associates (1984), p. 20.

Neither the ineffective low-cost gadgets nor the high efficiency hardware are appropriate for most homes. Instead, the use of simple hardware and some lifestyle adjustments may suffice to improve indoor air qualities in the home. Some suggested adjustments[1] are listed below.

COMMON SENSE & LIFESTYLE

Air Supply -	ensure a fresh air source, i.e. avoid intakes near motor vehicle traffic or trash storage
Aerosol Spray -	discontinue or use with an effective exhaust fan
Chemical Cleaners -	store outside, reduce use, e.g. try substitutes such as sodium bicarbonate (baking soda)
Deodorizers -	avoid, as odour counteraction products are air quality counterproductive
Food Preparation -	decrease frying - increase boiling, raw foods and pressure cooking
Footwear -	remove at door as they are vectors of street dirt (a mixture of chemical and biological wastes)
Personal Hygiene -	reduce vapour by using hand-held shower nozzles, electric hair dryers produce motor emissions and warmth may accelerate vapour release of hair and skin cosmetics, use non-aerosol shave creams and non-electric razors
Smoking -	direct exhaust to outdoors if smoking continues
Lighting Combustibles-	use butane lighters which are relatively cleaner than sulfates etc. from matches
Materials -	use materials, furniture etc. which are low pollutant emitters

CONTROL OF APPLIANCES

Combustion -	use adequate ventilation and exhaust for each source, electronic ignitions versus pilot lights on gas stoves, ducted exhaust fans with humidistat or thermally activated fan switches

(1) K.H. Raab, "Low Technology Strategies for Residential Indoor Air Quality" in Indoor Air, Vol. 5, Swedish Council for Building Research, Sweden, 1984, p. 157-164.

Moisture Sources -	clean humidifier baths and refrigerator drain pans frequently

PARTICULATE REMOVAL

Ducted Houses -	incorporate air treatment and filtration systems
Filtration -	use medium efficiency (35%-55%, ASHRAE 52-76) pleated fabric filters which are an order of magnitude better than the common furnace filter and less expensive in the long term
Unducted Houses -	add ducting and filters
Apartments -	employ portable exhaust fans and air changers; tall narrow windows should open top and bottom

For further details and an example of a house and an attached office which was designed and constructed for low levels of indoor pollution, see a report prepared by Bruce Small for CMHC.(1)

B. Commercial Sector

The commercial sector has relied heavily on a systems approach in energy conservation. HVAC systems, which often sacrificed efficiency to allow precise control of conditions in individual zones of buildings, have been and continue to be easily modified, resulting in savings of up to 50% of total energy consumption. To date, the costs often associated with the resultant decrease in air quality have not been adequately compared.

Standards for ventilation are one means of attempting to reduce indoor air pollutants, but even ASHRAE, in recognition of the indoor air quality problems and associated health and discomfort symptoms, recommends the opening of windows in office buildings when the conditions are favourable.(2) Within this constraint of conservation various aspects of ventilation can be successful in reducing indoor contaminants.

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(1) Bruce M. Small and Associates Ltd., Indoor Air Pollution and Housing Technology, prepared for Planning Division Policy Development and Research Sector, Canada Mortgage and Housing Corporation (CMHC), August 1983, 295 p.

(2) S.J. Bell and B. Khati, "Indoor Air Quality in Office Buildings" in Occupational Health in Ontario, Vol. 4, no. 3, July 1983, p. 115.

1. Ventilation System Design[1]

The supply of oxygen is usually not a problem if ventilation is provided for dilution, pressurization or heat dissipation. The control of a contaminant is more of a concern, especially with respect to local concentrations. In these cases, the use of a properly designed local exhaust may be the most cost-effective solution to the control of indoor air quality. Figure 3 illustrates general principles of dilution ventilation. The first six designs are examples of poor fan locations where localized contaminants from a work-bench will be drawn into the worker's breathing zone. The last six designs illustrate good fan locations with correct and incorrect air inlet or make-up air locations. The best air inlet uses a plenum to distribute make-up air over a large area.

2. Particle Removal Devices

Cellulose, fabric and glass-fibre filters are the devices most often used for particle removal, the type often dependent on the particular applications under consideration. ASHRAE has recommended several standard tests for evaluating their performances based on mass collection efficiency, collection efficiency for sub-micron particles and pressure drop. In general as the arrestance or efficiency increases so will pressure drop and the need for stronger air flow and higher energy costs are incurred.

Use of electrostatic precipitation in electronic air cleaners reduces the problems of pressure drop and has a relatively high efficiency for submicron-sized particles such as exist in tobacco smoke. The drawbacks of these cleaners are that they require regular cleaning, have a higher initial cost than most filter arrangements and they will also produce ozone. In such cases, it is advantageous to combine particulate removal with gas cleaning by an absorber which catalytically converts ozone to oxygen,[2]

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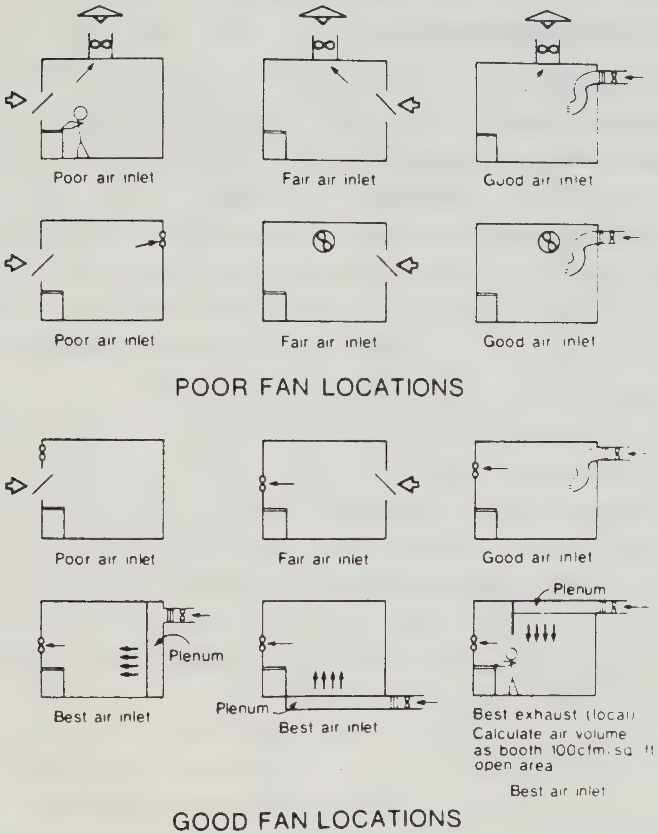
(1) Note: All references in subsections 1 to 4 are from Wadden and Scheff (1983), p. 135-168, unless otherwise noted.

(2) A. Turk, "Gaseous Air Cleaning Can Help Maintain Tolerable Indoor Air Quality Limits", in ASHRAE Journal, May 1983, p. 35.

FIGURE 3: INLET AND EXHAUST VENTILATION AIR AND EXHAUT LOCATIONS



Source: R.A. Wadden and P.A. Scheff, Indoor Air Pollution: Characterization, Prediction and Control, John Wiley and Sons Inc., New York, 1983, p. 150.

(see "Gas Filters and Traps" section). Other types of electronic air cleaners incorporate charged (dielectric) collection media with or without dust charging in an ionizer.

3. Gas Filters and Traps

Adsorption, absorption, incineration and catalytic conversion are all removal techniques for pollutant gases. Adsorption is probably the most frequent control of small quantities of gaseous materials causing odour or other discomfort problems. For most applications, activated carbon (activated charcoal) is the adsorbent of choice as it is less selective than other materials and adsorbs non-polar or weakly polar organic compounds, even from humid atmospheres. A variety of adsorption bed designs exist but thin bed adsorbers appear to have a greater capacity for pollutant removal than do carbon impregnated designs.

Activated carbon is by no means the total answer to gas removal. Lighter gases, such as ammonia and formaldehyde, will not be efficiently adsorbed and may require the impregnation of the adsorbent with a chemical agent that will react with a specific pollutant gas. For example sodium sulfate on activated charcoal is effective for formaldehyde gas removal. Another problem is that the effective life of adsorption beds, dependent on a multitude of factors such as gas types, concentrations and air flow rates, is not easily calculated.

4. Air Conditioning

Although air conditioning serves primarily as a heat control device, it does affect indoor air quality. Pollen concentrations are significantly reduced and other particulate matter appears to be slightly reduced. One study, however, suggests that the effect of cigarette smoke particles is more persistent with air conditioning, due to the recirculation. Reactive gases such as SO_2 may also be reduced because of absorption by condensed moisture on heat exchanger coils, but CO tends not to be affected. As mentioned earlier, air conditioning can also serve to concentrate infections organisms present in outdoor air.

DISCUSSION

Indoor air pollution consists of outdoor pollution penetrating indoors and of indoor generated pollutants. Ventilation systems, both directly as regulators of air exchange rates and indirectly either in a filtering capacity or as a contaminant source, play a strong role in the control of indoor air quality. Even though reassessment indicates that windows that open, or a greater air exchange rate with clean outside air is a simple solution to most indoor air quality problems, energy conservation is still observed as the number one priority. It is however, becoming obvious that the comfort and health of building occupants are of growing concern. This may be for humanitarian (or legal) reasons as well as a realization of the immense loss of productivity due to the poor health, welfare and comfort of building occupants.

As well as the control of ventilation, the control of contaminant sources is fundamental to providing good indoor air quality. Most experts in the field of indoor air quality have either implicated or stressed the seriousness of passive smoking. In most cases, it is felt to be the single most important issue in the "sick building syndrome". It should also be possible to reduce contaminant emissions by the construction of a notification system which permits the selection of products with the least impact on human health and comfort, and consequently with the lowest need for ventilation. Such preventive measures, although complex, appear possible according to the experience of the Danish National Inventory of Toxic Substances and Products.(1)

Indoor air quality might be viewed as only one aspect which affects the mental or physical well being of an individual in an office environment. At present the Architectural and Building Sciences (ABS) of Public Works Canada feels that deficiencies in aural/acoustic quality, visual/illumination quality, thermal and air quality, building amenities and selection and arrangement of furniture can rapidly fatigue office

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(1) I. Andersen et al. (1982), p. 11-16.

workers. They propose that standards related to these parameters and scaled to the individual at the micro-building level must be developed.(1)

Indoor air quality, affecting 80% to 90% of the average individual's life is a problem which cannot be further ignored.

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(1) Architecture and Building Sciences; A Pilot Study and a Micro-Environment Building Performance Application, FUNDI draft report, Public Works Canada, 27 April 1985, p. 1.

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